(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 752 185 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
17.07.2002 Bulletin 2002/29

(21) Application number: **95914709.1**

(22) Date of filing: **13.03.1995**

(51) Int Cl.[7]: **H04N 5/455**, H04N 5/44, H04N 7/015, H04L 27/02, H04L 27/06

(86) International application number:
PCT/US95/03155

(87) International publication number:
WO 95/26101 (28.09.1995 Gazette 1995/41)

(54) **CARRIER RECOVERY SYSTEM FOR A VESTIGIAL SIDEBAND SIGNAL**

TRÄGERRÜCKGEWINNUNGSSYSTEM FÜR EIN RESTSEITENBANDSIGNAL

SYSTEME DE RECONSTITUTION DE PORTEUSE POUR SIGNAL A BANDE LATERALE RESIDUELLE

(84) Designated Contracting States:
DE FR GB IT

(30) Priority: **21.03.1994 GB 9405487**

(43) Date of publication of application:
08.01.1997 Bulletin 1997/02

(73) Proprietor: **RCA Thomson Licensing Corporation**
Princeton, NJ 08540 (US)

(72) Inventors:
- **STROLLE, Christopher, Hugh**
  Glenside, PA 19038 (US)
- **JAFFE, Steven, Todd**
  Freehold, NJ 07729 (US)

(74) Representative: **Ruellan-Lemonnier, Brigitte**
THOMSON multimedia,
46 quai A. Le Gallo
92648 Boulogne Cédex (FR)

(56) References cited:
US-A- 3 674 929
US-A- 3 800 228
US-A- 3 849 730
US-A- 4 048 572
US-A- 5 410 368

- **ZENITH & AT&T TECHNICAL DETAILS, "Digital Spectrum Compatible", 23 September 1991, pages 58-84.**

Description

Field of the Invention

[0001] This invention concerns a digital signal processing system. In particular, the invention concerns a carrier recovery system for use in a receiver of a vestigial side band (VSB) signal such as may be modulated with high definition television (HDTV) information, for example.

Background of the Invention

[0002] The recovery of data from a VSB or a QAM (Quadrature Amplitude Modulated) signal at a receiver requires the implementation of three functions: timing recovery for symbol synchronization, carrier recovery (frequency demodulation) and equalization. Timing recovery is the process by which the receiver clock (timebase) is synchronized to the transmitter clock. This permits the received signal to be sampled at the optimum point in time to reduce the chance of a slicing error associated with decision-directed processing of received symbol values. Carrier recovery is the process by which a received RF signal, after being frequency shifted to a lower intermediate frequency passband, is frequency shifted to baseband to permit recovery of the modulating baseband information. Equalization is a process which compensates for the effects of transmission channel disturbances upon the received signal. More specifically, equalization removes baseband intersymbol interference (ISI) caused by transmission channel disturbances including the low pass filtering effect of the channel. ISI causes the value of a given symbol to be distorted by the values of preceding and following symbols.

[0003] For QAM signals, timing recovery is usually the first function implemented in a receiver. The timing is recovered from either the intermediate passband signal or from a near-baseband signal, i.e., a baseband signal with a carrier offset that is corrected by a carrier recovery network. In either case, timing can be established prior to baseband demodulation. The carrier recovery demodulation process is usually a two step process. First, the passband signal is demodulated to near-baseband by a frequency shifter which uses a "best guess" as to what the frequency offset is between the incoming passband signal and the desired baseband signal. This frequency shift is usually performed by analog circuits; i.e., prior to analog to digital conversion in the receiver. Next, equalization is performed on this near-baseband signal. Finally, carrier recovery is performed which removes any residual frequency offsets from the near-baseband signal to produce a true baseband output signal. This function is performed by digital receiver circuits. The equalizer is inserted between a first local oscillator which performs the shifting to near-baseband, and the carrier recovery loop network. This is because the carrier recovery process typically is a decision-directed process (as known) that requires at least a partially open "eye" which is provided by the equalizer function.

[0004] A QAM signal is represented by a two-dimensional data symbol constellation defined by Real and Imaginary axes. In contrast, a VSB signal is represented by a one-dimensional data symbol constellation wherein only one axis contains quantized data to be recovered at a receiver. Synchronous demodulation of a VSB signal has usually been accomplished with the aid of a pilot signal. The pilot signal facilitates demodulating the VSB signal to baseband in one step, typically without residual phase or frequency errors. Performing the functions of timing recovery, demodulation and equalization in the order they are performed for QAM signals does not work for VSB signals using conventional techniques. For QAM signals, several timing recovery methods are known which are independent of the frequency offset between the near-baseband signal and the baseband signal. However, it is generally accepted that frequency independent timing recovery is not feasible for VSB signals. For this reasons, in VSB systems, absolute demodulation to baseband has historically been implemented first.

[0005] In a pilot-assisted VSB system, the pilot component is injected into the baseband signal at the transmitter as a small DC offset. This DC offset generates a carrier "tone" because when the DC offset is multiplied by an alternating signal such as in the form of a high frequency cosine function, a similarly phased carrier tone results. This carrier tone can be used by a phase locked loop (PLL) in the receiver demodulator to translate the modulated VSB signal to baseband. Since the pilot represents the DC component of the VSB signal, and this DC component is in the middle of the vestigial sideband, the tone appears to be situated in the middle of modulation "noise" caused by the data itself. Normally this modulation noise is treated as unwanted signal for the pilot tracking PLL at the receiver.

[0006] The pilot can be extracted by means of a very narrow bandpass filter prior to the PLL. However, this requires a filter with such a narrow bandwidth to achieve sufficient data noise rejection that the tracking PLL is not capable of tracking all phase and frequency offsets of the incoming signal, especially when consumer grade tuners are used. Shifting the pilot component to baseband is not done easily in the digital domain. If analog circuits are used, problems of compensation for tolerances and temperature effects, for example, will have to be addressed. The pilot component also wastes power, and it is possible that a transmission channel perturbation such as a channel null will cancel the pilot. For these and other reasons, it is herein recognized as desirable to provide a system capable of demodulating a VSB signal to baseband without relying on a pilot component of the received signal.

[0007] One example of a VSB system including a pilot component is the Grand Alliance HDTV transmission

system recently proposed for the United States. This system employs a VSB digital transmission format for conveying a packetized datastream, and is being evaluated in the United States by the Federal Communications Commission through its Advisory Committee of Advanced Television Service (ACATS). A description of the Grand Alliance HDTV system as submitted to the ACATS Technical Subgroup on February 22, 1994 (draft document) is found in the 1994 Proceedings of the National Association of Broadcasters, 48th Annual Broadcast Engineering Conference Proceedings, March 20-24, 1994.

[0008] The document US-A-3,849,730 concerns a system for coherent detection of vestigial-sideband, amplitude-modulated data signals.

Summary of the Invention

[0009] In accordance with the principles of the present invention, a carrier recovery demodulation system suitable for use with VSB signals advantageously achieves carrier recovery without reliance on a pilot signal or an equivalent signal. This is accomplished using a filter network and a phase detector responsive to output signals from the filter network. The filter network has a band edge response with respect to at least one of upper and lower band edges of the VSB signal frequency spectrum, for producing a suppressed carrier double sideband amplitude modulated (AM) signal at the output of the filter network.

[0010] In particular, an object of the invention is, an apparatus for receiving a high definition television (HDTV) signal transmitted as a modulated vestigial sideband (VSB) signal formatted as a one-dimensional data constellation of symbols representing digital image data and subject to exhibiting a carrier offset, including an input network having a tuner for receiving said VSB signal, circuitry for frequency shifting said received VSB signal toward baseband, and a carrier recovery network capable of achieving carrier recovery without reliance on a pilot component if present in said received signal, said apparatus being characterized by:

a band edge filter network responsive to the output signal from said input network and having a band edge response with respect to at least one of upper and lower band edges of a frequency spectrum of said VSB signal for producing a double sideband amplitude modulated (AM) signal at an output of said filter network;

a phase detector network responsive to a carrier offset of said double sideband AM output signal to produce a control signal (Δ) representing a carrier offset when present; and

frequency translating means coupled to the received VSB signal and responsive to said control signal for producing a demodulated output signal at or near baseband.

[0011] In accordance with a feature of the invention, the filter network comprises first and second digital band edge filters having band edge responses respectively associated with upper and lower band edges of the VSB signal frequency spectrum for producing double sideband amplitude modulated signals at respective outputs of the first and second filters. The filter responses are complementary to the frequency spectrum of said received VSB signal at the band edge that the fist and second filters are respectively filtering.

Brief Description of the Drawings

[0012] In the drawing:

Figure 1 is a block diagram of a portion of an advanced television receiver, such as a HDTV receiver, including a carrier recovery system in accordance with the principles of the invention.

Figures 2-6 illustrate amplitude versus frequency responses of signals associated with the operation of the system of Figure 1.

Detailed Description of the Drawings

[0013] In Figure 1, a broadcast VSB modulated HDTV analog signal received by an antenna 10 is processed by an input network 14 including RF tuning circuits, a double conversion tuner for producing an intermediate frequency passband suitable for conversion to digital form and appropriate gain control circuits, for example. The received VSB signal illustratively is an 8-VSB signal with a symbol rate of approximately 10.76 Msymbols/second occupying a conventional NTSC 6 MHz frequency spectrum, in accordance with the Grand Alliance HDTV specification. Specifically, the received VSB signal in this example is an 8-VSB signal having a one dimensional data constellation defined by the following eight data symbols:

-7 -5 -3 -1 1 3 5 7

The Nyquist bandwidth for this system is nominally 5.38 MHz for example, with excess bandwidth of nominally 0.31 MHz at each bandedge. The disclosed system may also be used for 16-VSB signals, for example.

[0014] The output signal. from input processor 14 is converted from analog to digital form by an analog-to-digital converter 16, which operates at a sample rate of 2 samples/symbol. The received VSB signal may include a pilot component and has been demodulated by unit 14 so that the center of the 6 MHz band is nominally situated at 5.38 MHz. The frequency spectrum of this signal at the input of ADC 16 occupies a range of 2.38 MHz to 8.38 MHz. When timing synchronization is established, ADC unit 16 samples this signal at 21.52 MHz, which is twice the symbol rate. The pilot component, which represents the DC point of the original baseband pulse amplitude modulated (PAM) signal, is nominally situated at 2.69 MHz (the Nyquist frequency),

which is 1/8 f_{sr}. In the following discussion

f_c is the carrier frequency of the transmitted signal (nominally 5.38 MHz),

f_{st} is the transmitted symbol frequency (10.76 Msymbols/sec, or four times the Nyquist frequency), and

f_{sr} is the receiver sampling frequency (21.52 Mhz). At timing lock, $f_{sr} = 2f_{st}$. At carrier lock when demodulation to baseband results, f_c = 1/4 f_{sr}.

[0015] The digital signal from ADC unit 16 is applied to two complex bandedge filters 20 and 22, which are mirror image filters around the Nyquist frequency. Each filter exhibits real and imaginary functions so that output signals from these filters contain real and imaginary components. In Figure 1, a letter "C" designates those signal paths which convey complex signals with real and imaginary components. Other signal paths convey only real components. Filters 20 and 22 produce output signals without image components, i.e., the output signals contain either positive or negative spectral components but not both. This has the advantage of not generating spurious components that may be difficult to remove subsequently. In this system filters 20 and 22 are designed to have complex analytic output signals with negative spectral components as will be seen from Figure 2. The negative spectrum is arbitrary; the positive spectrum also could have been chosen.

[0016] Figure 2 depicts the negative frequency spectrum encompassed by the bandpass responses of filters 20 and 22, and by the bandwidth of the received VSB signal as applied to the inputs of filters 20 and 22. The input real signal has positive and negative spectra. The positive spectrum is cancelled using known techniques, leaving the negative spectrum. Filter 20 extracts the upper bandedge of the negative spectrum of the VSB signal, and filter 22 extracts the lower bandedge of the negative spectrum of the VSB signal. The upper bandedge is that which contains the highest frequency components, regardless of whether they are positive or negative components. The lower bandedge is associated with the lowest frequency components. The bandedge responses of filters 20, 22 and the VSB signal intersect at the Nyquist points. In Figure 2 and subsequent Figures, a symbol "Δ" designates a carrier frequency offset such as may be associated with a near-baseband signal, i.e., a signal not completely frequency shifted to baseband. This offset will be discussed in detail in connection with the carrier recovery (baseband demodulation) network.

[0017] The responses of filters 20 and 22 are complementary to the frequency spectrum of the input signal at the bandedge the filters are extracting, as shown in Figure 2. This has the effect of producing a double sideband suppressed carrier amplitude modulated (AM) signal when no pilot component is present in the received VSB signal (Figure 3), and producing a double sideband residual carrier AM signal when a pilot is present in that bandedge. The response of filter 20 to the left of frequency f_1 is not critical, and the response of filter 22 to the right of frequency f2 is not critical.

[0018] Prior to establishing timing and carrier lock, these AM signals contain frequency (and phase) offsets that may be used for timing and carrier recovery. Specifically, the center of the AM signal obtained from the output of upper bandedge filter 20 is situated at $-f_c$-1/4 f_{st}. If a pilot signal is present (such as in the Grand Alliance HDTV system), it would appear at this frequency. The frequency 1/4 f_{st} is one-fourth the symbol frequency if the signal is treated as a VSB signal. Similarly, the center of the AM signal obtained from the output of the lower bandedge filter is situated at $-f_c$ + 1/4 f_{st} (the Nyquist frequency). Timing synchronization is achieved when the frequency of the sampling clock input (CLK) of ADC unit 16 is four times the frequency difference between the carriers of these two upper and lower suppressed carrier band edge AM signals (Figure 3).

[0019] The timing recovery system operates as follows. The output signal from filter 22 is conjugated by unit 25 to flip the spectrum of the filter 22 output signal from negative to positive. This is illustrated by Figure 4. Conjugation is a well-known process performed in unit 25 by first separating the signal into its real and imaginary components using well-known methods. The imaginary component is inverted by multiplying it by a negative unity factor. The inverted imaginary component and the original real component are re-combined. The recombined lower bandedge AM signal is multiplied with the upper bandedge AM signal from filter 20 in multiplier 26. An AM signal produced at the output of multiplier 26 has carrier frequency component f_c removed, as illustrated by Figure 5. Removal of this f_c component results because the negative carrier of the upper bandedge component cancels the positive carrier of the conjugated AM signal from the lower bandedge. The AM signal at a suppressed carrier center frequency of 1/2 f_{st} is maintained because both of the multiplied AM signals are double sideband signals. In the frequency domain these signals are represented at baseband as even functions (i.e., as real only components), and their convolution is represented at baseband as even valued functions.

[0020] The bandwidth of the AM output signal from multiplier 26 has been doubled by the convolution process (multiplication in time produces convolution in frequency). By driving every other sample to zero, the frequency of the receiver sampling clock CLK can be synchronized to the symbol frequency of the input VSB signal independent of any carrier offset (Δ). This is accomplished by a phase detector 28 in a timing recovery network 30 as follows.

[0021] The imaginary component of the double sideband AM output signal from multiplier 26 (Figure 5) is an indication of the magnitude of signal mis-timing. The real component indicates the direction of the mis-timing

(AM suppressed carrier signals have an ambiguity of 180 degrees which is to be resolved). If this AM signal is perfectly timed, the imaginary component is absent. The double sideband AM signal from multiplier 26 is separated into its constituent real and imaginary components by means of a unit 32 in phase detector 28 using known separation techniques. Using known techniques, a translation unit 34 determines the sign of real component (for direction information), and multiplies this sign by the separated imaginary component samples. The output of multiplier 36 represents an error signal which is driven to zero by the action of the timing control loop when timing lock is achieved.

[0022] Since the carrier frequency of the double sideband signal is nominally situated at 1/2 f_{sr}, at lock of the imaginary component of the output signal from multiplier 36 will be zero. Multiplying the imaginary component with the sign of the real component gives phase detector 28 the ability to differentiate between positive and negative frequency offsets.

[0023] The output signal from phase detector 28 is filtered by a low pass loop filter 38 which contains both an integral path and a proportional path, as known, and is clocked at a frequency of 1/2 f_{sr}. Loop filter 38 is clocked to process every other sample of the input signal since the purpose of the loop is to drive every other sample of the imaginary component to zero. The output of filter 38 is a DC voltage which is applied to a voltage controlled oscillator (VCO) 40. Oscillator 40 provides the receiver sampling clock CLK for ADC unit 16 as a function of the DC voltage. Timing synchronism is achieved when the ADC sampling clock provided by the described timing recovery system including network 30 is four times the frequency difference between the carriers of the two AM output signals from filters 20 and 22 (Figure 3). The proportional and integral control portions of filter 38 are adjustable as known by using K1 and K2 gain control scalars respectively. These scalars are set to large values to facilitate signal acquisition in the acquisition mode, and may be reduced in value during the tracking mode to increase noise immunity. The time required to achieve timing lock varies as a function of the amount of noise and multipath distortion present in the signal, the control loop bandwidth, and the control loop time constants, for example.

[0024] The carrier can be recovered using two different methods in the system of Figure 1. One method uses both of the bandedge AM signals from the outputs of filters 20 and 22 in a manner that is similar to that described above for timing recovery. The second method uses only one bandedge of the received signal. In the second case, typically the bandedge which is used is that which may contain the pilot. The extra energy associated with the pilot component enhances the performance of the carrier recovery loop in low signal-to-noise conditions. It is noted, however, that both of these methods advantageously do not require the presence of a pilot component.

[0025] The carrier recovery method using both band edges multiplies the outputs of filters 20 and 22 together in a multiplier 45 without conjugating the signal as was done for timing recovery. This multiplication produces a suppressed carrier AM signal at the output of multiplier 45 with a carrier frequency of $-2f_c$. The symbol rate component f_{st} has been completely removed from this AM signal. If a carrier offset (Δ) exists, the carrier frequency is at $-2f_c-2\Delta$ as depicted in Figure 6. Up to this point, the carrier recovery process is independent of the receiver demodulator sampling clock frequency, f_{sr}.

[0026] In digital signal processing applications, it is generally desirable to design voltage controlled oscillators (VCO_s) or spectral shifters that conveniently produce signals which are harmonically related to the clock frequency of the digital signal processor. In this regard it is noted that the complex double sideband AM signal at the output of multiplier 45 (Figure 6) is centered at a frequency of $-2f_c$ (neglecting any carrier offset), or at $-2fc-2\Delta$ (including the offset). This means that this AM signal is straddling the aliasing foldover region. More specifically, in practice, the left sideband portion of the AM signal shown in Figure 6 actually "wraps around" into the positive frequency spectrum. Aliasing does not occur because this AM signal is a complex signal in which the adjacent positive frequency component of the first negative repeat band has been removed.

[0027] To simplify the design of the carrier recovery network, an associated phase detector 54 is essentially the same as phase detector 28 used in timing recovery network 30. In order to do achieve this, the carrier of the AM input signal to phase detector 54 must be driven to 1/4 f_{sr}. The carrier of the AM signal input to phase detector 54 is nominally shifted to a frequency of 1/4 f_{sr} by using a complex spectral shifter operating at +1/4 f_{sr}. The spectral shifter comprises complex multipliers 52 and 64. Multiplier 64 responds to a 1/4 f_{sr} sampling signal for shifting the output signal of VCO 62 by +1/4 f_{sr}. The response of VCO 62 is similar to VCO 40 in the timing control loop, and responds to a DC voltage produced by a low pass loop filter 60 which is similar to filter 38 in the timing recovery loop. A resulting complex output signal from multiplier 64, which contains the frequency offset generated by the loop plus the fixed 1/4 f_{sr}, is applied to an input of complex multiplier 52. The other input of multiplier 52 receives the AM signal centered at $-2f_c$ from the output of complex multiplier 45.

[0028] Phase detector 54 operates the same as phase detector 28 in the timing recovery loop. Phase detector 54 includes a real/imaginary component separator 55, a sign function translation network 56, and an output multiplier 57. Phase detector 54 operates by multiplying the imaginary component of the output signal from multiplier 52 with the sign of the real component. This causes the value of every other sample of the imaginary component to be driven to zero. Since phase detector 54, like phase detector 28, operates on the same set of samples (i.e., odd or even, but not both),

loop filter 60 (like filter 38) is required to supply output samples at the symbol rate rather than at twice the symbol rate. This significantly reduces the complexity of the loop filters compared to what would be required for 2 sample per symbol implementations.

[0029] The output of multiplier 45, at the input to carrier recovery network 50, is a complex double sideband suppressed carrier AM signal centered at a frequency $-2f_c-2\Delta$. The output of VCO 62 in the carrier loop is a signal approximately equal to 2Δ. To produce this signal at the output of VCO 62, a signal 1/4 f_{sr} is added to the carrier loop via multiplier 64 to cancel the $2f_c$ component. The complex signal 2Δ at the output of VCO 62 is translated to an output signal Δ of carrier recovery network 50 by means of a divide-by-2 frequency divider 70. Output signal Δ is a tone (without a frequency spectrum) representing the carrier phase/frequency offset.

[0030] The VSB output signal from ADC unit 16 is applied to an input of multiplier 74 after being delayed by a unit 72, which compensates for the signal delay through filters 20 and 22. The output of delay unit 72 is a complex near baseband symmetrical double sideband VSB signal as depicted by the frequency spectrum diagram adjacent to block 72. This signal is shifted to closer to baseband by multiplier 74, which is clocked at 1/8 f_{sr} to produce a near baseband upper VSB sideband at its output, as depicted by the frequency spectra diagram at the output of multiplier 74. The near baseband VSB signal from the output of multiplier 74 is applied to one input of a complex multiplier 71, and the output (offset representative) signal Δ from the output of carrier recovery network 50 is applied to another input of multiplier 71. The function of multiplier 71 is to substantially cancel the offset Δ in the VSB signal so that a baseband VSB signal results.

[0031] A complex demodulated VSB signal appearing at the output of multiplier 71 should be at baseband and often is. However, in practice this signal may contain residual phase offsets that may have to be compensated for. This is accomplished by an equalizer 75, which may be of a known configuration. Equalizer 75 compensates for channel disturbances as known and produces an equalized output signal that is decoded by unit 76 and processed by an output processor 78. Decoder 76 may include, for example, trellis decoder, de-interleaver, Reed-Solomon error correction, and audio/video decoder networks as known. Output processor 78 may include audio and video processors and audio and video reproduction devices.

[0032] Carrier recovery can also be accomplished using a single band edge of the input signal, as follows. Lower band edge filter 22 produces a double sideband AM output signal with a carrier frequency of $-f_c + 1/4\, f_{st}$. This is accomplished by setting the input to multiplier 45 from filter 20 to a value of unity. This may be done by placing a multiplexer in the signal path between the output of filter 20 and the upper input of multiplier 45. One input of the multiplexer receives the output signal from filter 20, and another input receives a unity value signal. The latter signal is conveyed to the input of multiplier 45 in response to a control signal applied to a control input of the multiplexer. The output signal from upper band edge filter 20 is decoupled from multiplier 45 when the unity value signal is employed. In a system using two band filters, timing and carrier lock may occur at about the same time. In a system using only one band edge filter, carrier lock may occur after timing lock, depending on a variety of factors such as noise, loop gain and loop bandwidth.

[0033] If timing lock has been established by network 30, then $f_{st} = 1/4\, f_{sr}$, and the f_{st} component of the carrier can be removed by shifting the AM output signal of filter 22 with a -1/8 f_{sr} spectral shifter. This spectral shifting is accomplished in Figure 1 by changing the illustrated 1/4 f_{sr} clock input to multiplier 64 to a -1/8 f_{sr} clock. After such spectral shifting, the AM signal carrier at the output of multiplier 52 will be at a frequency $-f_c$ (in contrast to $-2f_c$ in the case of the double band edge method discussed previously).

[0034] In this embodiment the AM signal carrier frequency f_c can be easily driven to -1/4 f_{sr} by using a phase detector similar to unit 54 used for the double band edge carrier recovery example and forcing every other sample of the real component to zero. The output of the phase detector is integrated by a low pass loop filter which drives a VCO in a loop which acts to drive the AM signal carrier frequency to -1/4 f_{sr} in a manner analogous to that described above in connection with the double band edge carrier recovery example.

[0035] In the described embodiments, timing recovery (lock) may be achieved even in the presence of a carrier offset, and timing lock does not rely on sync components in the VSB signal for this purpose. Moreover, carrier recovery is accomplished without reliance on a pilot component. The choice of operating phase detectors 28 and 54 at the midpoint of the Nyquist region is one possible implementation. However, the phase detectors could also be operated at baseband with the same results. The use of the negative frequency spectrum is arbitrary. The positive spectrum could also have been used with analogous results, by using a different implementation of the described circuits. For example, conjugate filters 20 and 22 would be used and the input to multiplier 64 would be -1/4 f_{sr}.

Claims

1. Apparatus for receiving a high definition television (HDTV) signal transmitted as a modulated vestigial sideband, VSB, signal formatted as a one-dimensional data constellation of symbols representing digital image data and subject to exhibiting a carrier offset, including an input network having a tuner for receiving said VSB signal, circuitry for frequency shifting said received VSB signal toward baseband,

and a carrier recovery network capable of achieving carrier recovery without reliance on a pilot component if present in said received signal, said apparatus being **characterized by**:

a band edge filter network (20,22) responsive to the output signal from said input network (14) and having a band edge response with respect to at least one of upper and lower band edges of a frequency spectrum of said VSB signal for producing a double sideband amplitude modulated, AM, signal at an output of said filter network;

a phase detector network (54) responsive to a carrier offset of said double sideband AM output signal to produce a control signal (Δ) representing a carrier offset when present; and

frequency translating means (71, 74) coupled to the received VSB signal and responsive to said control signal for producing a demodulated output signal at or near baseband.

2. An apparatus according to claim 1, wherein said filter network comprises a first band edge filter (20) and a second band edge filter (22) having band edge responses respectively associated with upper and lower band edges of a frequency spectrum of said VSB signal for producing double sideband amplitude modulated (AM) signals at respective outputs of said first and second filters.

3. An apparatus according to claim 1, wherein said filter network is a digital filter network comprising first and second filters with responses that are complementary to the frequency spectrum of said received VSB signal at band edges said first and second filters respectively filter.

4. An apparatus according to claim 1, wherein said received VSB signal exhibits a frequency spectrum with band edge responses at a frequencies f_c - 1/4 f_{st} and f_c + 1/4 f_{st} respectively, with respect to a mid-band carrier frequency f_c +/- Δ; and said first filter exhibits a band edge response at a Nyquist frequency f_c - 1/4 f_{st} and said second filter exhibits a band edge response at a Nyquist frequency f_c + 1/4 f_{st}, where

f_c is the carrier frequency of said transmitted VSB signal;

f_{st} is the transmitted symbol frequency; and

Δ is said carrier offset when present.

5. An apparatus according to claim 2 and further including a multiplier (45) having first and second inputs for receiving output signals from said first and second filters, respectively, and an output coupled to an input of said phase detector network; wherein an output signal of said multiplier is a suppressed carrier double sideband AM signal (Fig. 6) centered around a frequency $2f_c$ where f_c is the carrier frequency of said transmitted VSB signal, said centered frequency subject to exhibiting a carrier offset (Δ).

6. An apparatus according to claim 1, wherein said input signal to said phase detector network is a complex signal having real and imaginary components; and said phase detector network includes means (55,56,57) for cancelling said imaginary component in an output signal from said phase detector network.

7. An apparatus according to claim 1, wherein said output processor comprises:

a first translating network (74) responsive to an output signal from said input network for producing a translated near baseband VSB signal; and

a second translating network (71) responsive to said near baseband VSB signal from said first translating network and responsive to said control signal from said carrier recovery network for producing a signal at or near baseband.

8. An apparatus according to claim 7 and further including an equalizer (75) for removing residual offsets from an output signal from said second translating network to produce a baseband VSB signal.

9. An apparatus according to claim 7 wherein said first and second translating networks are signal multipliers; and said first translating network receives an input VSB signal in double sideband form, and responds to a clock signal at a frequency related to f_{sr}, where f_{sr} is a receiver sampling frequency for producing an output single sideband near baseband VSB signal.

10. An apparatus according to claim 1, wherein said received VSB signal is an 8-VSB signal having a one dimensional data constellation defined by the following eight data symbols: - 7 -5 -3 -1 1 3 5 7.

Patentansprüche

1. Vorrichtung zum Empfang eines hochauflösenden Fernsehsignals (HDTV), das als eine eindimensionale Datenkonstellation von Symbolen formatiert

ist, die digitale Bilddaten darstellen und einem Trägerversatz unterliegen, mit einem Eingangsnetzwerk mit einem Tuner zum Empfang des VSB-Signals, einer Schaltung zur Frequenzverschiebung des empfangenen VSB-Signals in das Basisband und einem Trägerrückgewinnungs-Netzwerk, das in der Lage ist, eine Trägerrückgewinnung ohne Anwendung einer Pilotkomponente zu erreichen, wenn eine derartige in dem empfangenen Signal vorhanden ist, **gekennzeichnet durch folgende** Merkmale:

ein Bandkanten-Filternetzwerk (20, 22), das von dem Ausgangssignal des Eingangsnetzwek (14) gesteuert wird und einen Bandkantenverlauf für wenigstens eine der oberen und der unteren Bandkanten eines Frequenzspektrums des VSB-Signals aufweist, zum Erzeugen eines amplitudenmodulierten AM-Doppelseitenbandsignals an einem Ausgang des Filternetzwerks,
ein Phasendetektor-Netzwerk (54), das **durch** einen Trägerversatz des AM-Doppelseitenband-Ausgangssignals gesteuert wird und ein Steuersignal (Δ) erzeugt, das einen Trägerversatz darstellt, wenn dieser anwesend ist, und
Mittel (71, 74) zur Frequenzumsetzung, die mit dem empfangenen VSB-Signal gekoppelt sind und auf das Steuersignal ansprechen, zum Erzeugen eines demodulierten Ausgangsignals beim Basisband oder beim Nahezu-Basisband.

2. Vorrichtung nach Anspruch 1, wobei das Filternetzwerk ein erstes Bandkantenfilter (20) und ein zweites Bandkantenfilter (22) mit einem Bandkantenverlauf enthält, der jeweils zu der oberen und unteren Bandkante eines Frequenzspektrums des VSB-Signals gehört, zum Erzeugen der amplitudenmodulierten (AM)-Doppelseitenbandsignale an jeweiligen Ausgängen des ersten bzw. zweiten Filters.

3. Vorrichtung nach Anspruch 1, wobei das Filternetzwerk ein digitales Filternetzwerk ist, das ein erstes und ein zweites Filter mit Kennlinien enthält, die komplementär zu dem Frequenzspektrum des empfangenen VSB-Signals an den Bandkanten des ersten bzw. des zweiten Filters sind.

4. Vorrichtung nach Anspruch 1, wobei das empfangene VSB-Signal ein Frequenzspektrum mit einem Bandkantenverlauf bei Frequenzen f_c- $1/4f_{st}$ bzw. $f_c + 1/4f_{st}$ bezüglich einer Mittelband-Trägerfrequenz f_c+/-Δ aufweist, und
das erste Filter einen Bandkantenverlauf bei einer Nyquistfrequenz $f_c - 1/4f_{st}$ aufweist und das zweite Filter einen Bandkantenverlauf bei einer Nyquistfrequenz $f_c + 1/4f_{st}$ aufweist, wobei
f_c die Trägerfrequenz des übertragenen VSB-Signals ist,
f_{st} die übertragene Symbolfrequenz ist und
Δ der Trägerversatz ist, wenn dieser anwesend ist.

5. Vorrichtung nach Anspruch 2 mit folgenden Merkmalen:

eine Multiplizierstufe (45) mit einem ersten und einem zweiten Eingang zum Empfang von Ausgangssignalen von dem ersten bzw. dem zweiten Filter und einem Ausgang, der mit einem Eingang des Phasendetektor-Netzwerks verbunden ist, wobei
ein Ausgangssignal der Multiplizierstufe ein Doppelseitenband-AM-Signal mit unterdrücktem Träger (Figur 6) ist, das um eine Frequenz $2f_c$ zentriert ist, wobei f_c die Trägerfrequenz des übertragenen VSB-Signals ist und die Mittenfrequenz einen Trägerversatz (Δ) aufweist.

6. Vorrichtung nach Anspruch 1, wobei das Eingangssignal zu dem Phasendetektor-Netzwerk ein komplexes Signal mit einer realen und einer imaginären Komponente ist und
das Phasendetektor-Netzwerk Mittel (55, 56, 57) zur Beseitigung der imaginären Komponente in einem Ausgangssignal von dem Phasendetektor-Netzwerk enthält.

7. Vorrichtung nach Anspruch 1, wobei der Ausgangsprozessor enthält:

ein erstes Umsetznetzwerk (74), das auf ein Ausgangssignal von dem Eingangsnetzwerk anspricht, zum Erzeugen eines umgesetzten, Nahezu-Basisbandsignals VSB, und
ein zweites Umsetznetzwerk (71), das auf das Nahezu-Basisbandsignal VSB von dem ersten Umsetznetzwerk und auf das Steuersignal von dem Trägerrückgewinnungsnetzwerk anspricht, zum Erzeugen eines Signals bei oder in der Nähe des Basisbands.

8. Vorrichtung nach Anspruch 7 mit einem Entzerrer (75) zur Beseitigung der Restversatzanteile aus einem Ausgangssignal von dem zweiten Umsetznetzwerk, um ein Basisbandsignal VSB zu erzeugen.

9. Vorrichtung nach Anspruch 7, wobei das erste und das zweite Umsetznetzwerk Signal-Multiplizierstufen sind und
das erste Umsetznetzwerk ein Eingangssignal VSB in Form eines Doppelseitenbands emp-

fängt und auf ein Taktsignal bei einer Frequenz anspricht, die mit f_{st} verknüpft ist, wobei f_{st} eine Abtastfrequenz des Empfängers zum Erzeugen eines Nahezu-Basisband-Einseitenbandsignals VSB ist.

10. Vorrichtung nach Anspruch 1, wobei das empfangene VSB-Signal ein Signal 8-VSB mit einer dimensionalen Datenkonstellation ist, die durch die folgenden acht Datensymbole definiert ist:
-7 -5 -3 -1 1 3 5 7.

Revendications

1. Dispositif pour recevoir un signal de télévision de haute définition (THD) transmis sous forme de signal à bande latérale résiduelle, VSB, modulé, formaté en tant que constellation de données unidimensionnelle de symboles représentant des données d'images numériques et sujet à présenter un décalage de porteuse, comportant un réseau d'entrée ayant un circuit d'accord pour recevoir ledit signal VSB, des circuits pour déplacer en fréquence ledit signal VSB reçu vers la bande de base, et un réseau de récupération de porteuse capable de réaliser la récupération de porteuse sans compter sur une composante pilote si elle est présente dans ledit signal reçu, ledit dispositif étant **caractérisé par** :

   un réseau de filtres de bord de bande (20, 22) sensible au signal de sortie dudit réseau d'entrée (14) et ayant une réponse en bord de bande relativement à au moins un des bords de bande supérieur et inférieur d'un spectre de fréquences dudit signal VSB pour produire un signal modulé en amplitude AM à double bande latérale au niveau d'une sortie dudit réseau de filtres ;
   un réseau de détecteurs de phase (54) sensible à un décalage de porteuse dudit signal de sortie AM à double bande latérale afin de produire un signal de commande (Δ) représentant un décalage de porteuse s'il est présent ; et
   un moyen de translation de fréquence (71, 74) couplé au signal VSB reçu et sensible audit signal de commande pour produire un signal de sortie démodulé dans ou près de la bande de base.

2. Dispositif selon la revendication 1, dans lequel ledit réseau de filtres comprend un premier filtre de bord de bande (20) et un deuxième filtre de bord de bande (21) ayant des réponses en bord de bande respectivement associées aux bords de bande supérieur et inférieur d'un spectre de fréquences dudit signal VSB pour produire des signaux modulés en amplitude (AM) à double bande latérale à des sorties respectives desdits premier et deuxième filtres.

3. Dispositif selon la revendication 1, dans lequel ledit réseau de filtres est un réseau de filtres numériques comprenant des premier et deuxième filtres ayant des réponses qui sont complémentaires au spectre de fréquences dudit signal VSB reçu au niveau des bords de bande que lesdits premier et deuxième filtres filtrent respectivement.

4. Dispositif selon la revendication 1, dans lequel ledit signal VSB reçu présente un spectre de fréquences avec des réponses en bord de bande à des fréquences f_c - 1/4 f_{st} et f_c + 1/4 f_{st} respectivement, relativement à une fréquence porteuse à mi-bande f_c +/-Δ ; et
   ledit premier filtre présente une réponse en bord de bande à une fréquence de Nyquist f_c - 1/4 f_{st} et ledit deuxième filtre présente une réponse en bord de bande à une fréquence de Nyquist f_c + 1/4 f_{st}, où
   f_c est la fréquence porteuse dudit signal VSB transmis ;
   f_{st} est la fréquence des symboles transmis ; et
   Δ est ledit décalage de porteuse lorsqu'il est présent.

5. Dispositif selon la revendication 2 et comportant en outre
   un multiplicateur (45) ayant des première et deuxième entrées pour recevoir des signaux de sortie desdits premier et deuxième filtres, respectivement, et une sortie couplée à une entrée dudit réseau de détecteurs de phase ; dans lequel
   un signal de sortie dudit multiplicateur est un signal AM à double bande latérale à porteuse supprimée (figure 6) centré autour d'une fréquence $2f_c$, où f_c est la fréquence porteuse dudit signal VSB transmis, ladite fréquence centrée étant sujette à présenter un décalage de porteuse (Δ).

6. Dispositif selon la revendication 1, dans lequel ledit signal d'entrée dans ledit réseau de détecteurs de phase est un signal complexe ayant des composantes réelle et imaginaire ; et
   ledit réseau de détecteurs de phase comporte un moyen (55, 56, 57) pour annuler ladite composante imaginaire dans un signal de sortie dudit réseau de détecteurs de phase.

7. Dispositif selon la revendication 1, dans lequel ledit processeur de sortie comprend :

   un premier réseau de translation (74) sensible à un signal de sortie dudit réseau d'entrée pour produire un signal VSB presque en bande de

base translaté ; et

un deuxième réseau de translation (71) sensible audit signal VSB presque en bande de base provenant dudit premier réseau de translation et sensible audit signal de commande provenant dudit réseau de récupération de porteuse pour produire un signal en bande de base ou presque en bande de base.

8. Dispositif selon la revendication 7 et comportant en outre

un égaliseur (75) pour supprimer les décalages résiduels d'un signal de sortie provenant dudit deuxième réseau de translation afin de produire un signal VSB en bande de base.

9. Dispositif selon la revendication 7, dans lequel

lesdits premier et deuxième réseaux de translation sont des multiplicateurs de signaux ; et

ledit premier réseau de translation reçoit un signal VSB d'entrée sous forme de double bande latérale, et répond à un signal d'horloge à une fréquence liée à f_{sr}, où f_{sr} est une fréquence d'échantillonnage de récepteur pour produire un signal VSB presque en bande de base à bande latérale unique de sortie.

10. Dispositif selon la revendication 1, dans lequel

ledit signal VSB reçu est un signal VSB-8 ayant une constellation de données unidimensionnelle définie par les huit symboles de données suivants : -7 -5 -3 -1 1 3 5 7.

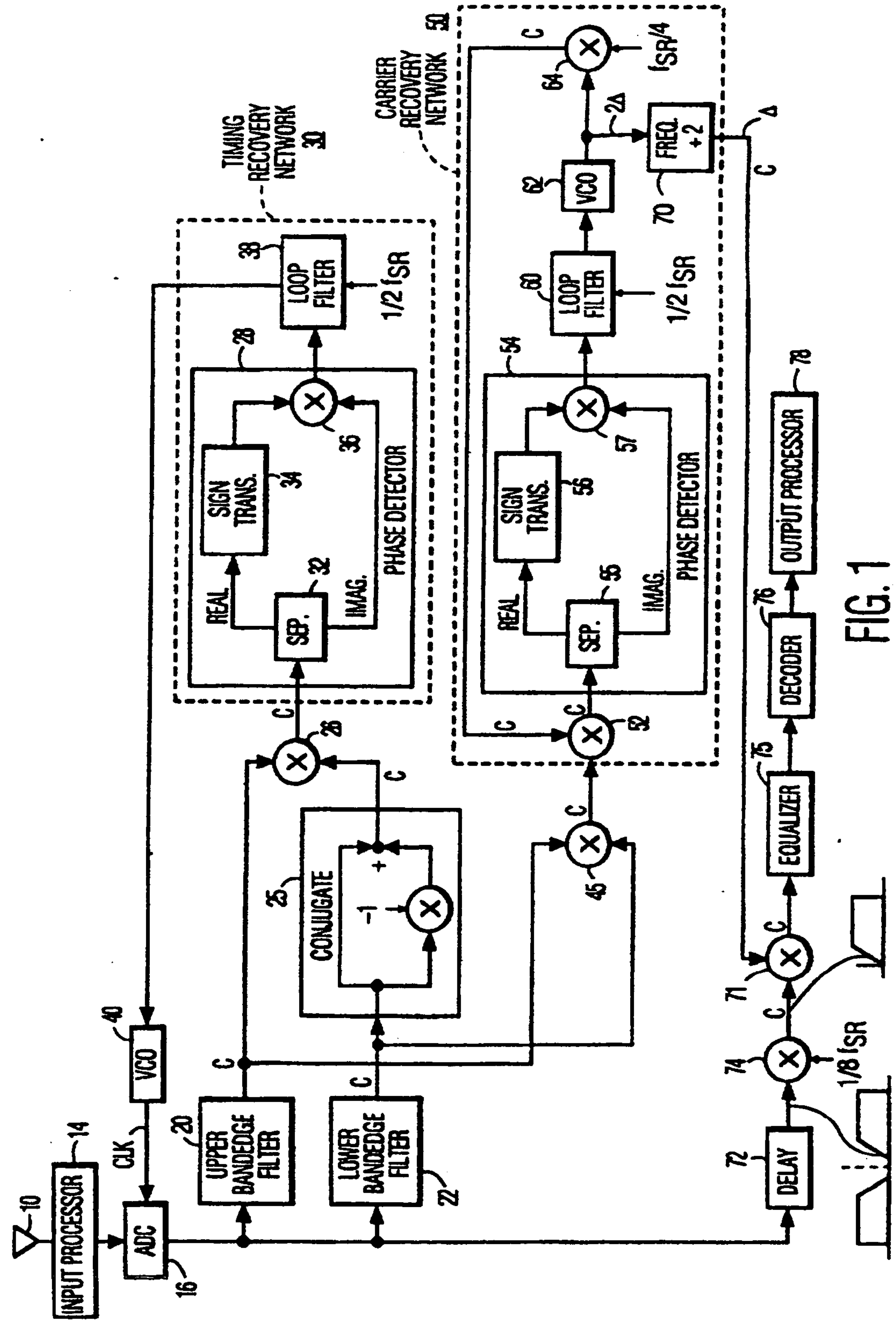
INPUT PROCESSOR
ADC
CLK
VCO
UPPER BANDEDGE FILTER
LOWER BANDEDGE FILTER
CONJUGATE
TIMING RECOVERY NETWORK 30
LOOP FILTER
1/2 fSR
SIGN TRANS.
SEP.
REAL
IMAG.
PHASE DETECTOR
CARRIER RECOVERY NETWORK
50
VCO
FREQ. ÷2
fSR/4
2Δ
Δ
DELAY
1/8 fSR
EQUALIZER
DECODER
OUTPUT PROCESSOR

FIG. 1

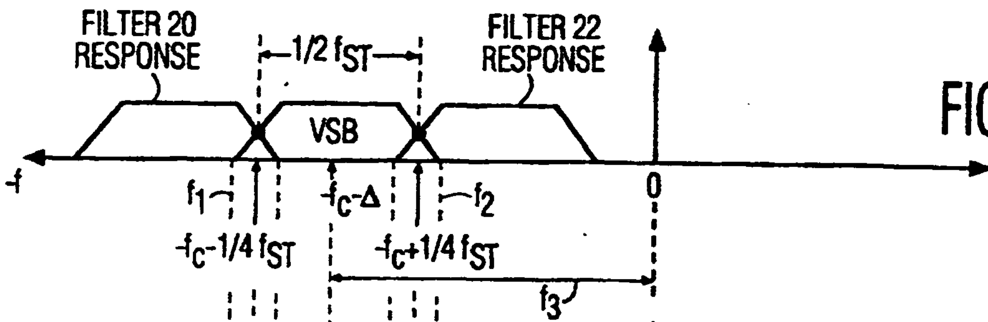

FIG. 2

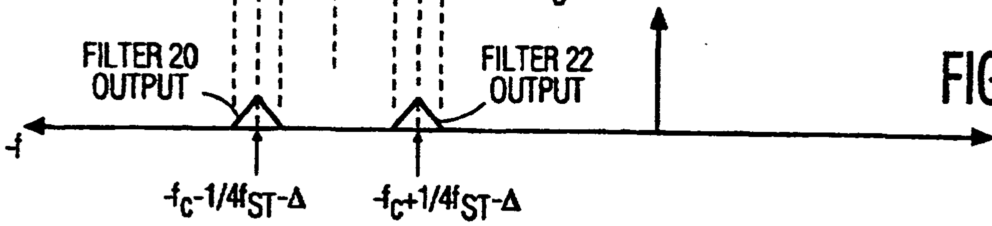

FIG. 3

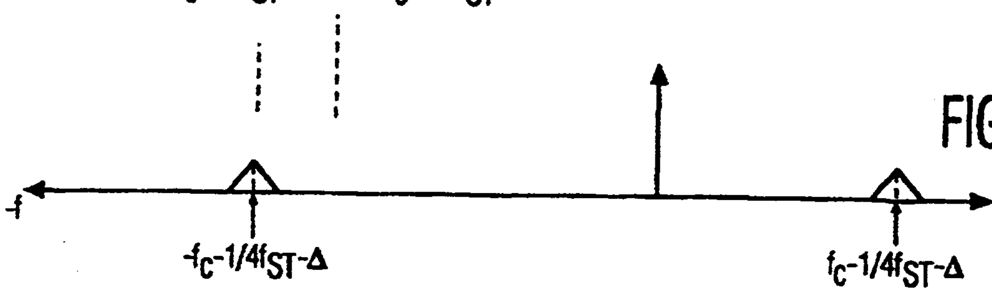

FIG. 4

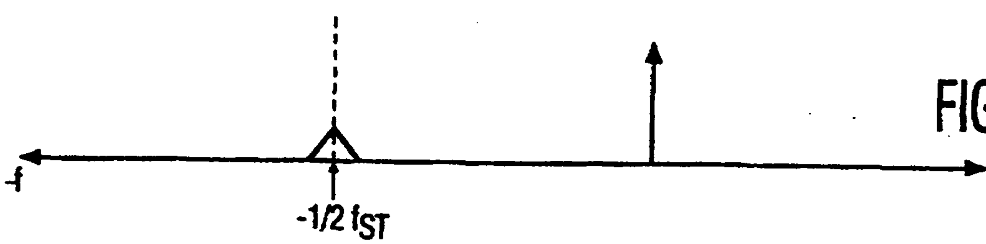

FIG. 5

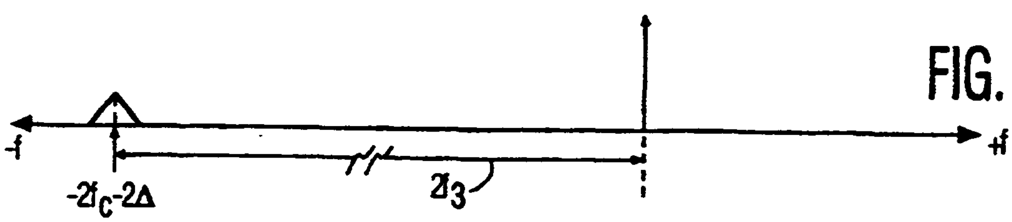

FIG. 6